Unparticle Phenomenology

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Collider Signals of Unparticle Physics

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Collider phenomenology of unparticle physics

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Fermilab seminar Oct 4, 2007

Ref.

H. Georgi, arXiv:0703.260, 1st pheno study

H. Georgi, arXiv:0704.2457, on propagator

Cheung,K,Yuan: arXiv:0704.2588, PRL

and 0706.3155 on production, propagator, and g-2

C.H. Chen and C.Q. Geng, on CP violation

M. Luo and G. Zhu, on spin-half

Fox et al on Scaling breaking by Higgs

Goldberg and Nath on Ungravity

M. Neubert on QCD emulating Unparticle

Freitas and Wyler on Astrophysical constraint

Banks and Zaks

$$\beta(g) = -\left(\beta_0 \frac{g^3}{16\pi^2} + \beta_1 \frac{g^5}{(16\pi^2)^2} + \beta_2 \frac{g^7}{(16\pi^2)^3}\right)$$

$$\beta_0 = 11 - \tfrac{4}{3} T(\mathrm{R}) N_{\mathrm{F}} ,$$

$$\beta_1 = 102 - (20 + 4C_2(\mathrm{R})) T(\mathrm{R}) N_{\mathrm{F}} ,$$

T. Banks, A. Zaks / Phase structure of vector-like gauge theories

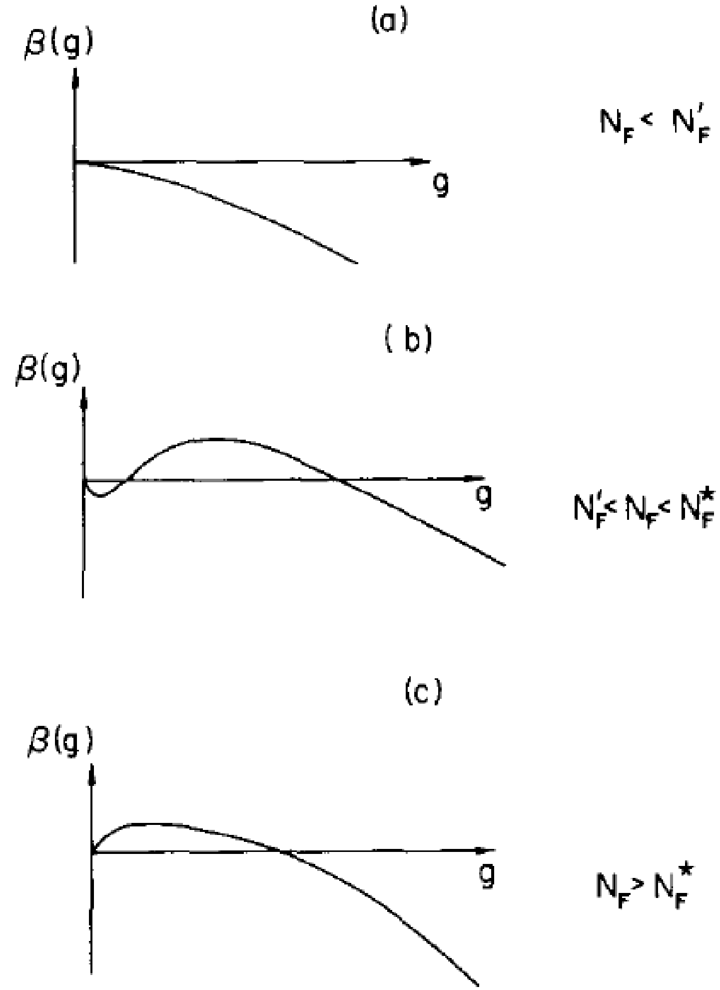


Fig. 1. 2 zero β function.

Phase Space and Spectral density

$$d_n(\text{PS of massless particles}) = A_n s_n^{n-2}\ , \quad A_n = \frac{16\pi^2\sqrt{\pi}}{(2\pi)^{2n}} \frac{\Gamma(n+\frac{1}{2})}{\Gamma(n-1)\Gamma(2n)}\ .$$

$$A_{n\to 1} = 2\pi(n-1)\ , \quad A_2 = \frac{1}{8\pi}\ , \quad A_3 = \frac{1}{256\pi^3}$$

$$A_n s^{n-1} \xrightarrow{n\to 1+\epsilon} \frac{2\pi\epsilon}{s^{1-\epsilon}} \to 2\pi\delta(s) \quad \epsilon\int_{0+}^{\infty} ds/s^{1-\epsilon} = s^{\epsilon}|_{0+}^{\infty} = 1.$$

$$\langle 0|O_{\mathcal{U}}(x)O_{\mathcal{U}}^{\dagger}(0)|0\rangle = \int \frac{d^4P}{(2\pi)^4} e^{-iP\cdot x}\, |\langle 0|O_{\mathcal{U}}(0)|P\rangle|^2 \rho(P^2)$$

$$|\langle 0|O_{\mathcal{U}}(0)|P\rangle|^2 \rho(P^2) \ = \ A_{d_{\mathcal{U}}}\, \theta(P^0)\, \theta(P^2)\, (P^2)^{d_{\mathcal{U}}-2}$$

$$\lambda_0 \frac{1}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} G_{\alpha\beta} G^{\alpha\beta} O_{\mathcal{U}} \quad , \quad \lambda_1 \frac{1}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}-1}}\, \bar{f}\gamma_\mu f\, O_{\mathcal{U}}^{\mu} \quad \lambda_2 \frac{1}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} G_{\mu\alpha} G_{\nu}^{\ \alpha} O_{\mathcal{U}}^{\mu\nu}$$

Scales

$$\frac{1}{M^{d_{SM}+d_{BZ}-4}}\mathcal{O}_{BZ}\mathcal{O}_{SM} \longrightarrow C\frac{\Lambda^{d_{BZ}-d_U}}{M^{d_{SM}+d_{BZ}-4}}\mathcal{O}_U\mathcal{O}_{SM}$$

$$\longrightarrow \underbrace{\left(C\frac{\Lambda^{d_{SM}+d_{BZ}-4}}{M^{d_{SM}+d_{BZ}-4}}\right)}_{\lambda}\frac{1}{\Lambda^{d_U+(d_{SM}-4)}}\mathcal{O}_U\mathcal{O}_{SM}$$

Example

$$\lambda_1\frac{1}{\Lambda^{d_u-1}}\bar{f}\gamma_\mu f\mathcal{O}^\mu \ , \quad \lambda_0\frac{1}{\Lambda^{d_u}}G^{\alpha\beta}G_{\alpha\beta}\mathcal{O} \ .$$

Production

$$\mathcal{O}_{\rm SM}\,\mathcal{O}_{\mathcal{BZ}}/M_{\mathcal{U}}^k \qquad (k>0)$$

$$(C_{\mathcal{O}_\mathcal{U}}\Lambda^{d_{\mathcal{BZ}}-d_\mathcal{U}}/M_\mathcal{U}^k)\,\mathcal{O}_{\rm SM}\,\mathcal{O}_\mathcal{U}$$

$$\begin{aligned} gg &\to g\mathcal{U}\,, \quad q\bar{q}\to g\mathcal{U}\,, \\ qg &\to q\mathcal{U}\,, \quad \bar{q}g \to \bar{q}\mathcal{U}\,. \end{aligned}$$

$$\frac{d^2\hat{\sigma}}{d\hat{t}dP_\mathcal{U}^2} = \frac{1}{16\pi\hat{s}^2}|\overline{\mathcal{M}}|^2\,\frac{1}{2\pi}\,A_{d_\mathcal{U}}\,\left(\frac{P_\mathcal{U}^2}{\Lambda_\mathcal{U}^2}\right)^{d_\mathcal{U}-2}\,\frac{1}{\Lambda_\mathcal{U}^2}$$

$$|\overline{\mathcal{M}}(gg\to g\mathcal{U})|^2 = \frac{1536\pi\alpha_s}{4\cdot 8\cdot 8}\,\lambda_0^2\frac{(P_\mathcal{U}^2)^4+\hat{s}^4+\hat{t}^4+\hat{u}^4}{\hat{s}\hat{t}\hat{u}\Lambda_\mathcal{U}^2}$$

Ellis, Hinchliffe, Sodate, Bij on the gg→gH

$$|\overline{\mathcal{M}}(q\bar{q}\to g\mathcal{U})|^2 = \frac{8}{9}g_s^2\lambda_1^2\,\frac{(\hat{t}-P_\mathcal{U}^2)^2+(\hat{u}-P_\mathcal{U}^2)^2}{\hat{t}\hat{u}}$$

$$|\overline{\mathcal{M}}(qg\to q\mathcal{U})|^2 = -\frac{1}{3}g_s^2\lambda_1^2\,\frac{(\hat{t}-P_\mathcal{U}^2)^2+(\hat{s}-P_\mathcal{U}^2)^2}{\hat{s}\hat{t}}$$

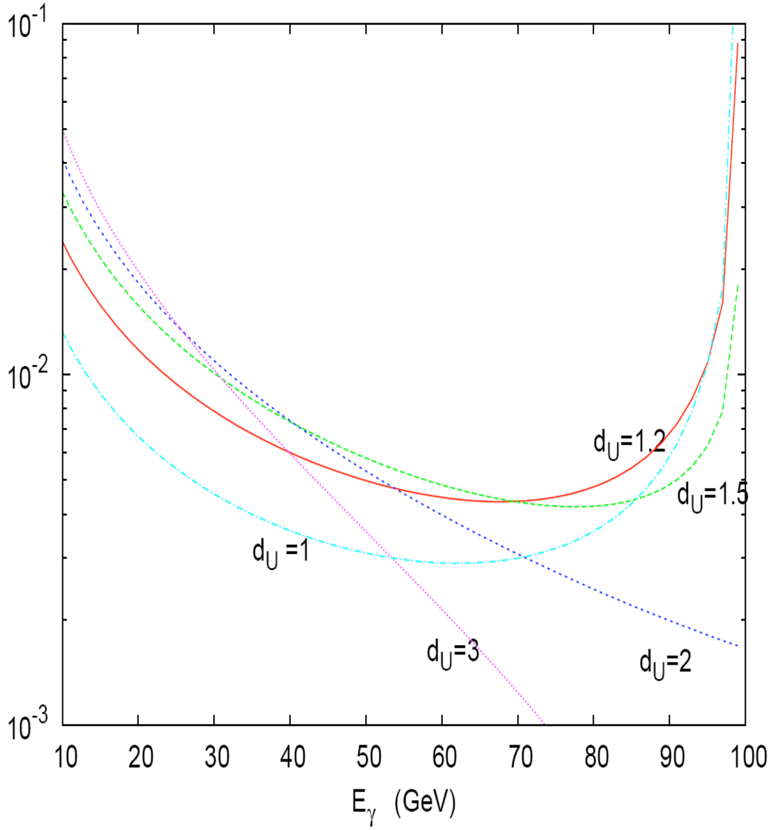
$$e^-(p_1)\,e^+(p_2)\ \to \gamma(k_1)\,\mathcal{U}(P_\mathcal{U})$$

$$|\overline{\mathcal{M}}|^2 = 2e^2Q_e^2\lambda_1^2\,\frac{u^2+t^2+2sP_\mathcal{U}^2}{ut}$$

$$d\sigma = \frac{1}{2s}\,|\overline{\mathcal{M}}|^2\,\frac{E_\gamma A_{d_\mathcal{U}}}{16\pi^3\Lambda_\mathcal{U}^2}\left(\frac{P_\mathcal{U}^2}{\Lambda_\mathcal{U}^2}\right)^{d_\mathcal{U}-2}\,dE_\gamma\,d\Omega$$

$$P_\mathcal{U}^2 = s - 2\sqrt{s}\,E_\gamma$$

distributions



: Normalized mono-photon energy spectrum of → $\gamma\mathcal{U}$ for $d_\mathcal{U} = 1$, 1.2, 1.5, 2 and 3 at $\sqrt{s} = 200$ GeV. e imposed $|\cos\theta_\gamma| < 0.95$.

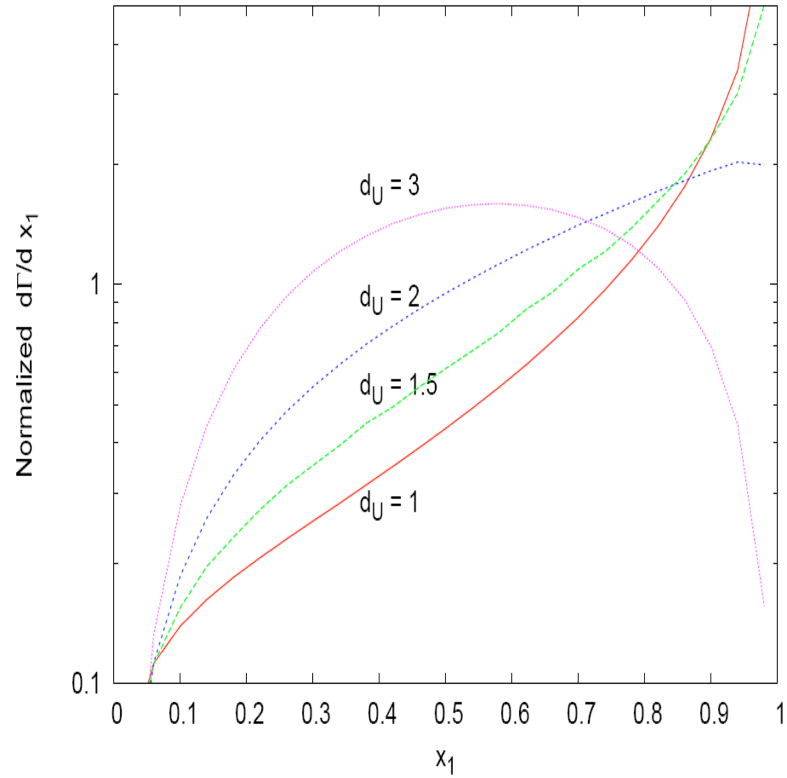


FIG. 1: Normalized decay rate of $Z \to q\bar{q}\mathcal{U}$ versus $x_1 = 2E_f/M_Z$ for different values of $d_\mathcal{U} = 1$, 1.5, 2, and 3.

LEP2 constraint

Experimental Constraint from LEP2

LEP Coll. have measured single-photon plus missing energy in the context of ADD, GMSB, and other models that can produce a single γ plus $\not{E}_T$ in the final state.

We use the strongest from L3 at $\sqrt{s} = 207$ GeV:

$$\sigma^{95} \simeq 0.2 \text{ pb under } \quad E_\gamma > 5\,\text{GeV}, \quad |\cos\theta_\gamma| < 0.97$$

Limits on $\Lambda_{\mathcal{U}}$ from single-photon production

$d_{\mathcal{U}}$	$\Lambda_{\mathcal{U}}$ (TeV)
2.0	1.35
1.8	4
1.6	23
1.4	660

Propagator

(4) Drell-Yan process: Virtual exchange of unparticle corresponding to the vector operator $O^{\mu}_{\mathcal{U}}$ can result in the following 4-fermion interaction

$$\mathcal{M}^{4f} = \lambda_1^2 \, Z_{d_{\mathcal{U}}} \, \frac{1}{\Lambda_{\mathcal{U}}^2} \left(- \frac{P_{\mathcal{U}}^2}{\Lambda_{\mathcal{U}}^2} \right)^{d_{\mathcal{U}}-2} (\bar{f}_1 \gamma_\mu f_2)\,(\bar{f}_3 \gamma^\mu f_4) \quad (11)$$

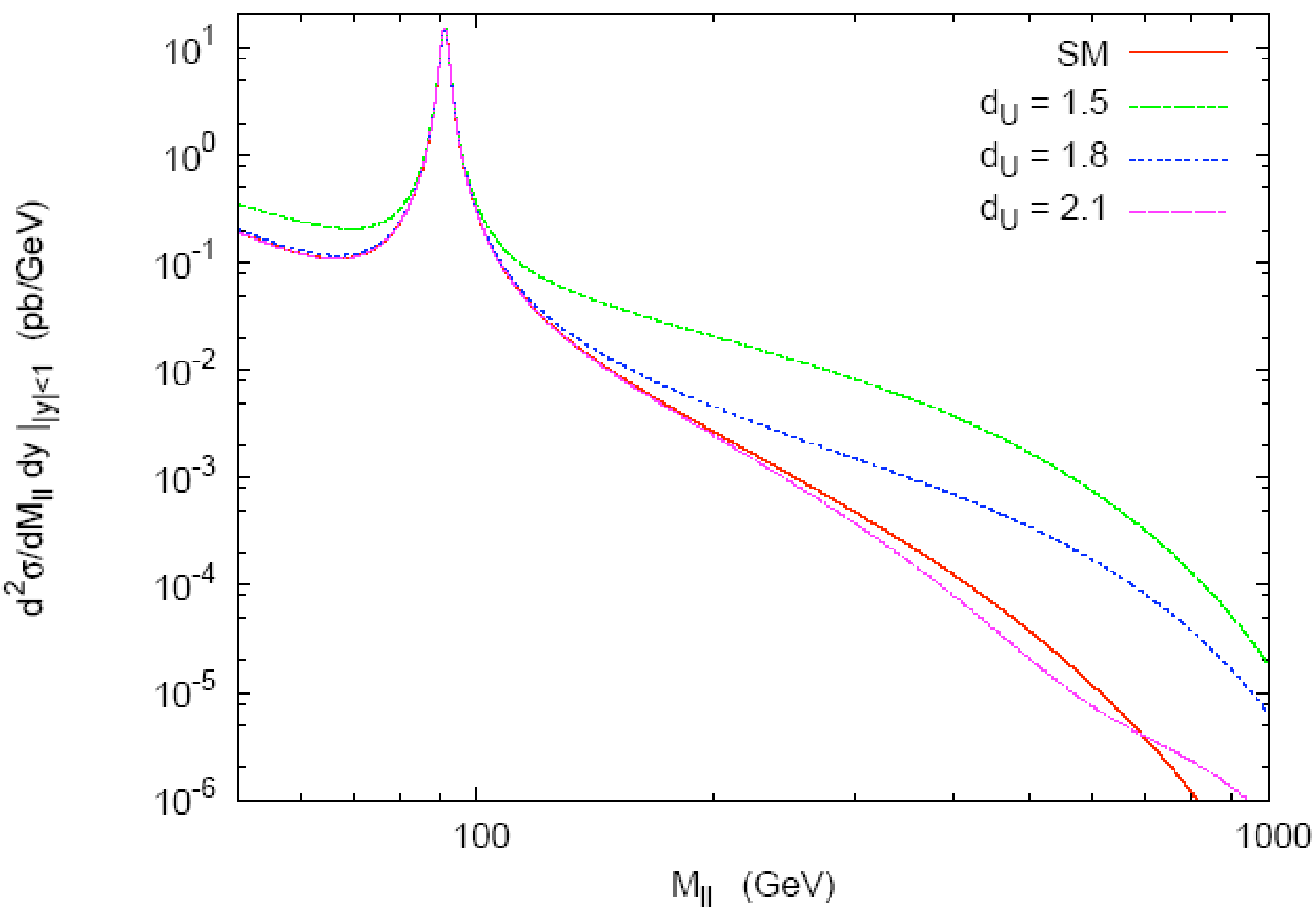
$$(re^{i\theta})^{d_{\mathcal{U}}-2} = r^{d_{\mathcal{U}}-2} e^{i\theta(d_{\mathcal{U}}-2)}$$

for $r > 0$ and $-\pi \le \theta < \pi$. Using the Källen-Lehmann spectral representation formula, one can derive $Z_{d_{\mathcal{U}}}$ as

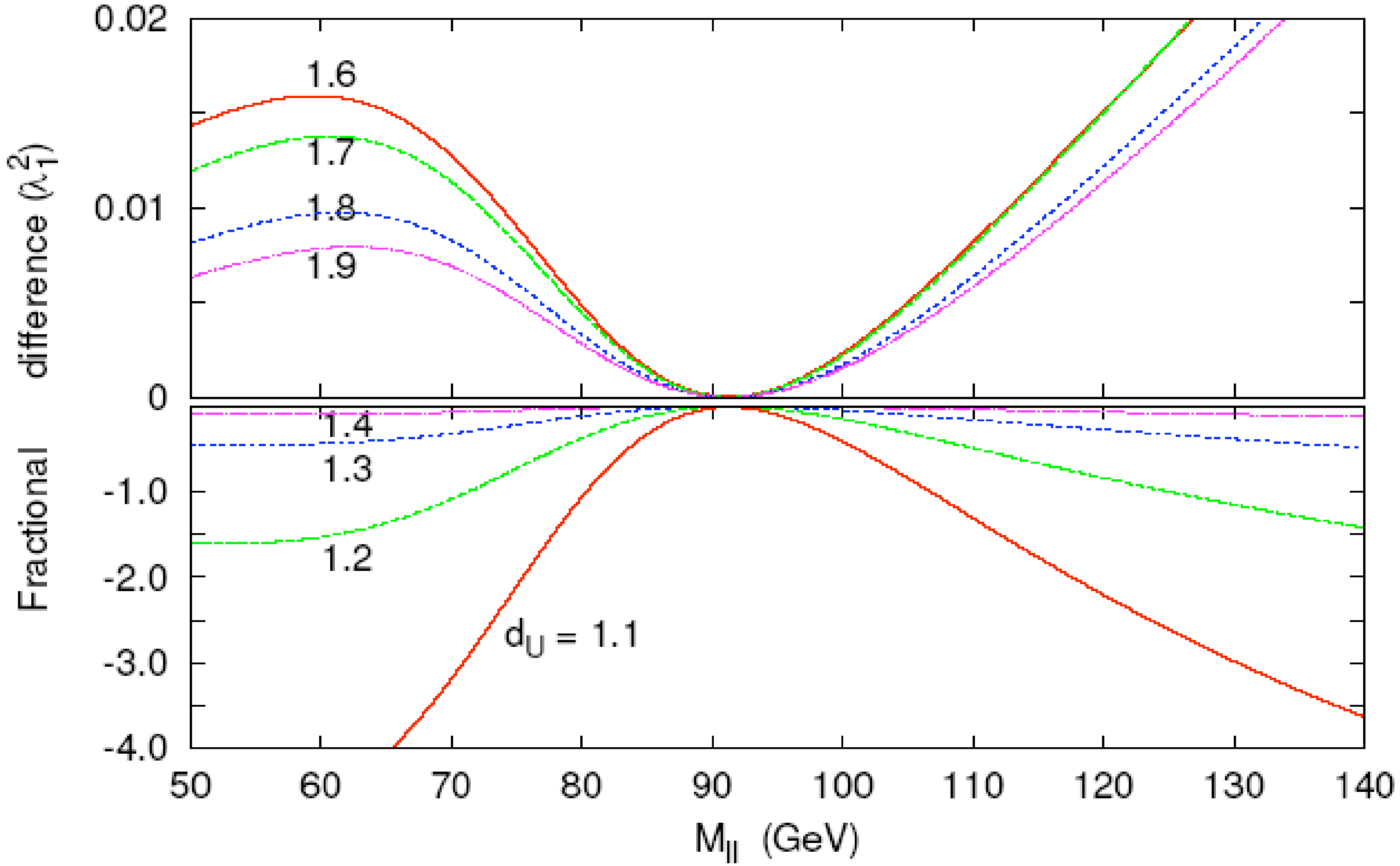
$$Z_{d_{\mathcal{U}}} = \frac{A_{d_{\mathcal{U}}}}{2\sin(d_{\mathcal{U}}\pi)} \quad \text{for} \quad d_{\mathcal{U}} < 2\,. \qquad (12)$$

The $(-)$ sign in front of $P_{\mathcal{U}}^2$ of the unparticle propagator in Eq.(11) gives rise to a phase factor $e^{-i\pi d_{\mathcal{U}}}$ for time-like momentum $P_{\mathcal{U}}^2 > 0$, but not for space-like momentum $P_{\mathcal{U}}^2 < 0$. Note that $P_{\mathcal{U}}^2$ is taken as the $\hat{s}$ for an s channel

Drell -Yan

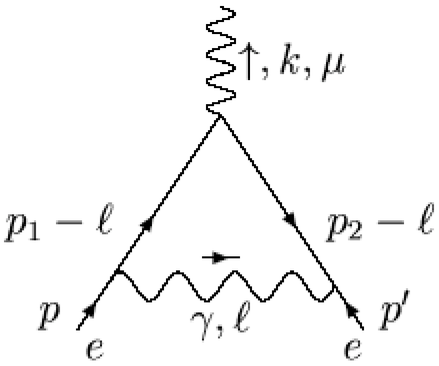

SM
d_U = 1.5
d_U = 1.8
d_U = 2.1
$d^2\sigma/dM_{ll}\, dy\, |_{|y|<1}$ (pb/GeV)
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
100
1000
M_{ll} (GeV)

Near Z



Interference of $\mathcal{U}$ with γ, Z propagators

g-2



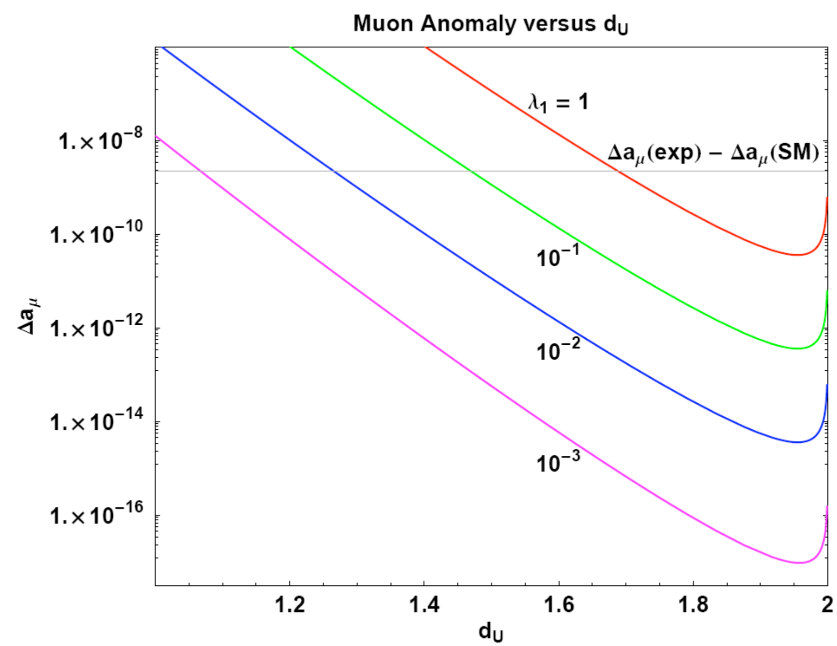
$$i\mathcal{M} = \frac{ie^3}{16\pi^2}\int \frac{q_E^2\, dq_E^2\, 4mi\sigma^{\mu k}}{-[q_E^2+(1-z)^2m^2]^3}\, z(1-z)\,dz\,dx$$

$$i\mathcal{M} = e\left(\frac{\alpha}{\pi}\right)\int_0^1 \frac{z\,dz}{1-z}\int_0^{1-z} dx\,\frac{\sigma^{\mu k}}{2m} = e\left(\frac{\alpha}{2\pi}\right)\frac{\sigma^{\mu k}}{2m}$$

$$-\frac{i}{16\pi^2}\int\frac{q_E^2\,dq_E^2}{(q_E^2+\mu^2)^{2+\beta}} = -\frac{i}{16\pi^2(\mu^2)^\beta}\int_0^\infty \frac{x\,dx}{(x+1)^{2+\beta}} = -\frac{i}{32\pi^2(\mu^2)^\beta}\left(\frac{2}{\beta(1+\beta)}\right)$$

$$\frac{1}{A_1A_2A_3^\beta} = \frac{z^{\beta-1}\,dx\,dy\,dz\,\delta(1-x-y-z)}{(xA_1+yA_2+zA_3)^{2+\beta}}\,\frac{\Gamma(2+\beta)}{(\beta)}$$

$$\boxed{a_U = \frac{\lambda_1^2}{4\pi^2}\left(-\frac{A_d}{2\sin(\pi d)}\right)\left(\frac{m^2}{\Lambda}\right)^{d-1}\frac{\Gamma(3-d)\Gamma(2d-1)}{(2+d)}}$$



Uncompton

$$d\sigma_L = \frac{1}{2}\left(\frac{\alpha}{m}\right)^2\sqrt{1-\frac{\mu^2}{\omega^2}}\left(\frac{\mu}{\omega}\right)^2 \sin^2\theta d\Omega$$

$$\sigma_T = \frac{8\pi\alpha^2}{3m^2}\sqrt{1-\mu^2/\omega^2}$$

$$\bar{\boldsymbol{\varepsilon}}'_L \cdot \boldsymbol{\epsilon}_\uparrow = (\mu/\omega)\sin\theta$$

$$\epsilon'_L = \mu^{-1}(\sqrt{\omega^2-\mu^2}, \omega\hat{\boldsymbol{k}}') \ , \quad \text{with } \epsilon'_L\cdot\epsilon'_L = -1 \ , \ \epsilon'_L\cdot k' = 0$$

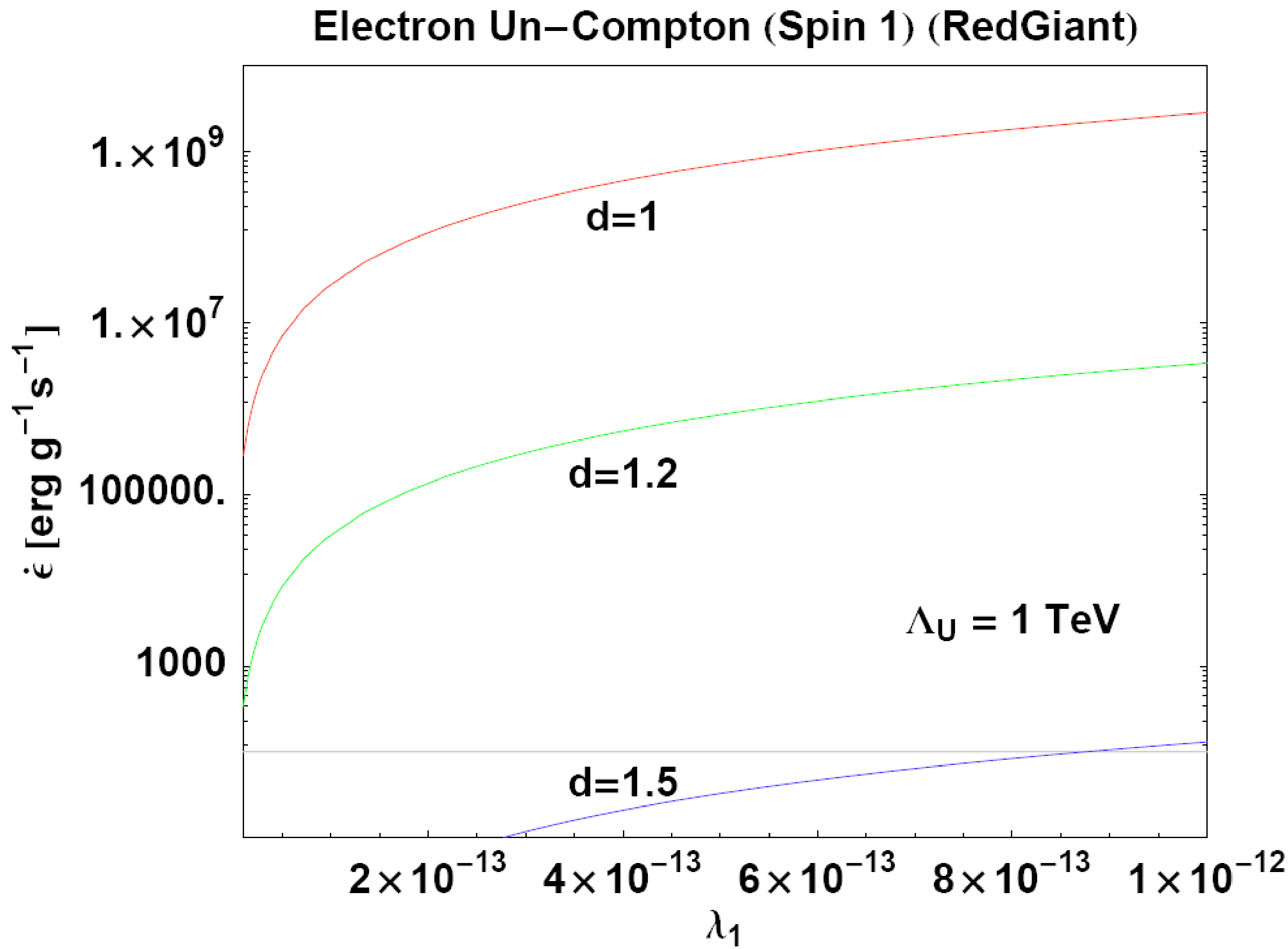
ϵ'_L by $\bar{\varepsilon}_L = \epsilon'_L - \beta k'$ $\beta = \frac{1}{\mu\omega}\sqrt{\omega^2-\mu^2}$ $\bar{\varepsilon}'_L = (0, \hat{\boldsymbol{k}}'\mu/\omega)$

$$\sigma_U = \int_0^{\omega^2} \frac{2\alpha\lambda_1^2}{3m_e^2}\sqrt{1-\frac{P^2}{\omega^2}}\left(1+\frac{1}{2}\frac{P^2}{\omega^2}\right)\frac{dP^2}{2\pi\Lambda^2}A_d\left(\frac{P^2}{\Lambda^2}\right)^{d-2}$$

$$L = \left\langle\frac{Z}{Am_N}\right\rangle\frac{2}{(2\pi)^3}\int E\frac{4\pi E^2 dE\sigma(E)}{\exp\left(\frac{E}{kT}\right)-1}$$

$$L = m_e^2\left\langle\frac{Z}{Am_N}\right\rangle\left(\frac{kT}{m_e}\right)^{2d+2}\left(\frac{m_e^2}{\Lambda^2}\right)^{d-1}\frac{\alpha\lambda_1^2}{3\pi^3}A_d[B(\tfrac{3}{2},d-1)+\tfrac{1}{2}B(\tfrac{3}{2},d)]\int_0^\infty\frac{x^{2d+1}dx}{e^x-1}$$

constraint



Electron Un−Compton (Spin 1) (RedGiant)
$1.\times10^9$
$1.\times10^7$
100000.
1000
$\dot{\epsilon}$ [erg g^{-1}s^{-1}]
d=1
d=1.2
d=1.5
Λ_U = 1 TeV
2×10^{-13}
4×10^{-13}
6×10^{-13}
8×10^{-13}
1×10^{-12}
λ_1

Conclusion

- What is the UNPARTICLE?
- Can it be deconstructed?
  (Stephanov)
- Is it more than a spectator in the EW sector?
- What is its role in cosmology?
  (Davoudiasl)

Unconstruction

$$E^2 = \mathrm{p}^2 + \sum_{i=1}^{n} (k_i)^2$$

$$\sum_{\vec{k}} \longrightarrow \int \left(\frac{L}{2\pi}\right)^n d^n k \;=\; \int \frac{L^n (m^2)^{\frac{n}{2}-1} dm^2}{(4\pi)^{\frac{n}{2}} \Gamma(\frac{n}{2})}$$

$$d_{\mathcal{U}} = \frac{n}{2} + 1$$

Fractional scaling dim, can be achived in AdS warp space (Stephanov)